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Author(s): **A. K. Zurek and D. A. Hunter**

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# DYNAMIC TESTING AND CHARACTERIZATION OF PRE-FRACTURED CERAMIC

**Anna K. Zurek and Dennis A. Hunter**
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Nearly all of the mechanical behavior studies of armor ceramics, to date, have involved the characterization and testing of pristine ceramic material. However, ballistic impact causes a strong shock front to propagate rapidly through the ceramic before much penetration can occur. A strong shock wave can result in localized compressive failure and fragmentation of the ceramic before its amplitude is attenuated below the compressive strength of the ceramic. The goals of this effort were to (1) create shock-fractured ceramic using test assemblies which maintain the intergranular coupling and high density of the ceramic, (2) characterize the extent and homogeneity of the fragmentation and dilatation of the ceramic, and (3) test the compressive dynamic behavior of the shock-fractured ceramic under conditions of confining pressure. This effort will provide data to support models of the penetration resistance of fractured ceramics including degraded moduli, failure strength-strain, and post-failure characterization of the erosive properties of comminuted ceramic and penetrator materials.

## INTRODUCTION

Dynamic characterization of ceramics has been of interest for the last ten years. Significant work has been done at the Southwest Research Institute, Honeywell Inc. Defense System Division, Los Alamos National Laboratory, and Sandia National Laboratory [1-6].

Ballistic impact causes a strong shock front to propagate rapidly through a ceramic before much penetration can occur. This shock wave can result in localized compressive failure of the ceramic before its amplitude is attenuated below the compressive strength of the ceramic. More importantly, since the tensile strengths of ceramics are very low relative to their compressive strengths, radial waves released from the sides of the ceramic section and axial tensile waves reflected from the rear interfaces can easily result in extensive fragmentation of the ceramic. In addition, confinement can have a major effect on the strength of a brittle material. In particular, the compressive failure strength generally increases significantly with confining pressure, a dependence that can be interpreted to establish empirically the relevant failure criterion for a given material. The confining pressure closes axial microcracks, slowing the crack coalescence process which ultimately causes a specimen to fail. Confinement also strengthens failed material, although to a much lesser extent than an unfailed ceramic. Hence, fractured but confined ceramics which have not lost intergranular coupling are considered to be more representative than unfailed ceramics of the materials which will ultimately interact with a penetrator during a ballistic impact.

The goals of this effort to characterize confined, shock-fractured ceramics are (1) to identify the confining pressure dependent strength, pre-fractured ceramic strength, and strain rate effects, (2) to develop a computational constitutive model which would include the effects of these parameters, (3) to incorporate the constitutive model into the EPIC code, and (4) to perform computations to compare the model with experimental results.

To achieve these goals, we created shock-fractured ceramic while maintaining the intergranular coupling and high density of the ceramic. We characterized the extent and homogeneity of the fragmentation and dilatation and tested the compressive dynamic behavior of the shock-fractured ceramic under conditions of confining pressure which was imposed by the constraint of a metal container.

This research will provide critical property data and phenomenological insight to support models of the penetration resistance of fractured ceramics including degraded moduli, failure strength strain, and post failure characterization of the erosive properties of comminuted ceramic on penetrator materials. After testing the number of ceramics, a property database will be developed to aid optimization of ballistic performance through microstructural tailoring of materials.

The initial results of the proposed research are presented below.

## RESULTS AND DISCUSSION

### *Ceramic Pre-Fracture in a Gas Gun Experiment*

Titanium diboride ($TiB_2$) samples were pre-fractured and tested under dynamic compression conditions. Each ceramic sample was contained in stainless steel with a plug to minimize loss in ceramic density. Shock waves were produced by a planar impact with a thick flyer plate in an 80 mm gas gun. These shock waves simulated a ceramic target impact inducing ceramic pulverization. Shock pressure and duration can be controlled, and the contained ceramic samples were shock loaded to 14GPa. Samples recovered from the pre-fracture experiments were characterized for density and crack distribution.

Figure 1 is a schematic of two pre-fracture test assemblies.

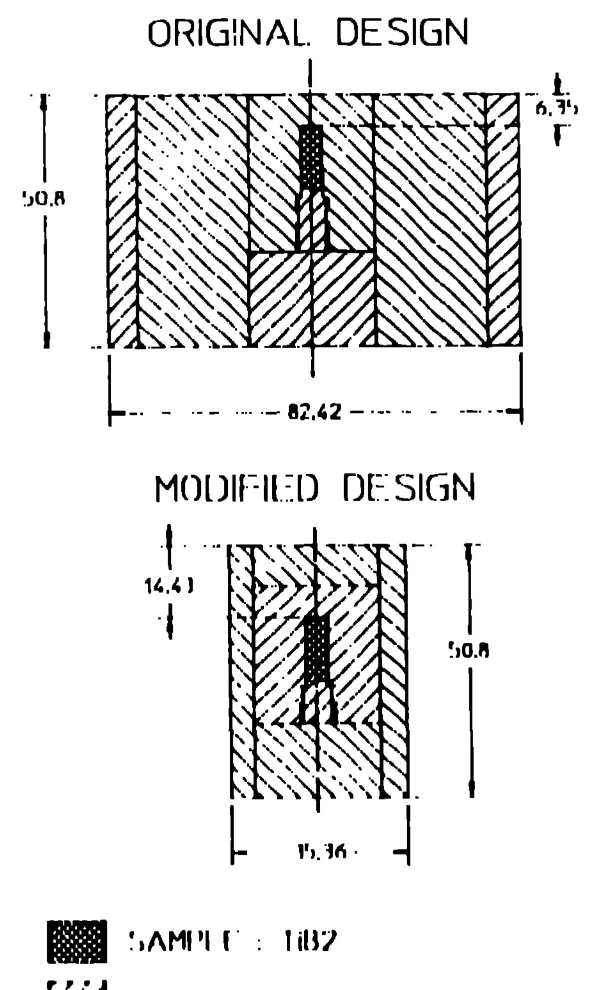


Fig. 1 Schematic of the original and improved pre fracture test assemblies.

Two difficulties were encountered using the first design. One was the interaction of radial release waves from the corner of the flyer plate with planar release waves from the back surface of the flyer plate. The other was radial distortion of the forward half of the steel container. The release wave interaction caused a high tension region which traversed a conical path into the stainless steel container and ceramic specimen. A forward conical spall developed in the stainless steel container at high impact velocities (1200 m/s), causing loss of ceramic containment. The container did not rupture at lower impact velocities (640 m/s), but as Figure 2 shows, a non uniform ceramic fracture results from the conical frontal spall.

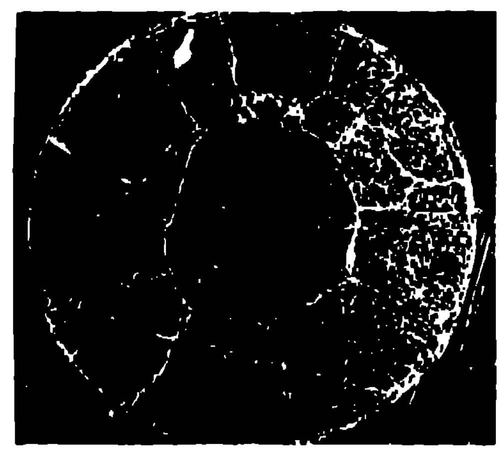

Fig. 2 Nonuniform fragmentation of the ceramic resulting from conical frontal spall.

The ceramic material inside the conical region remained nearly undisturbed while the material outside the cone was pulverized. The implication of this is that the ceramic withstood the initial compressive wave and fractured as a result of tensile waves occurring later in time. A cone of material was isolated from these waves by the release wave interaction. In order to obtain a uniformly fractured material, it was necessary to redesign the stainless steel container such that no part of the ceramic specimen was isolated in this manner. As shown in Figure 1, the diameter of the stainless steel container was reduced and the introduction of a stainless steel plug increased the distance of the ceramic specimen from the impact interface. These changes in the container placed the entire ceramic specimen beyond the tip of the conical region formed by the release wave interaction. The new design also placed the ceramic specimen beyond the region of drastic radial distortion in the container. Figure 3 shows a modeled schematic of the flyer plate and test assembly in which the lack of radial distortion around the specimen is apparent. Control of the radial distortion in this test is very important because it influences the density of the fractured ceramic.

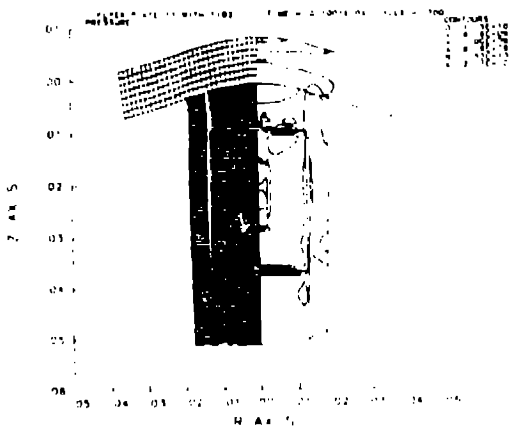

Fig. 3 A modeled schematic of the flyer plate and test assembly showing strains in the ceramic sample and stainless steel container.

As a result of the described planar impact, the fractured ceramic density was reduced only about 4%. Due largely to the very effective momentum trapping design of the fracture assembly, nearly theoretical density of the tested ceramic was maintained. Figure 4 shows polished front cross section of the ceramic fractured in the modified containment assembly.

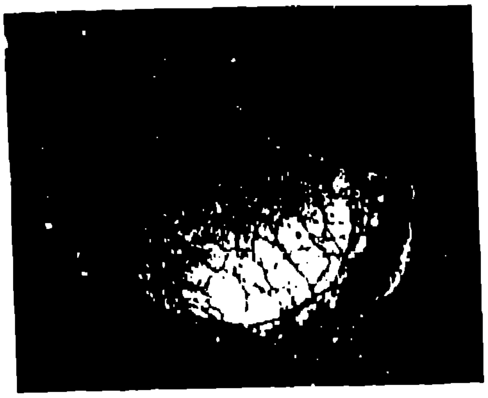

Fig. 4 A polished cross section of the ceramic fractured in a gas gun experimant using the modified containment assembly.

We expect a range in particle size through the sample due to wave interactions along the length of the sample. The size of the fractured particles in the ceramic ranged from 140 μm at the front of the sample to 100 μm at the back, as measured by the line intersection method.

*High Strain Rate Compression Test*

Tungsten plattens were used as load amplifiers in a Hopkinson Pressure Bar in the high strain rate compression test. The pre-fractured samples of $TiB_2$ were soft recovered from the gun test, and the stainless steel containers were machined down to the diameter of the tungsten plattens. Figure 5 is a schematic of a sample design tested using Hopkinson Pressure Bar.

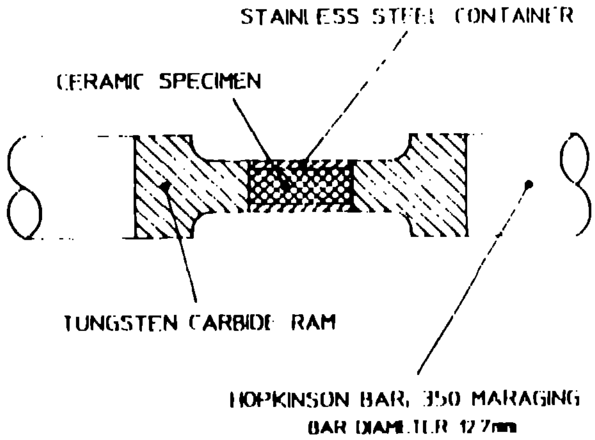


Fig 5 A schematic of sample design for high strain rate compression tests tested using Hopkinson Pressure Bar.

In this test, the pre shocked ceramic and the confining stainless steel tube were subjected to the same dynamic conditions. For calibration purposes, tests were also performed on solid $TiB_2$ in a stainless steel container, a pre shocked empty stainless steel container, and a pre shocked solid stainless steel cylinder. Both the empty stainless steel tube and solid stainless steel cylinder were fabricated from material recovered after the gun experiment. Figure 6 shows stress strain behavior from all of the high strain rate tests.

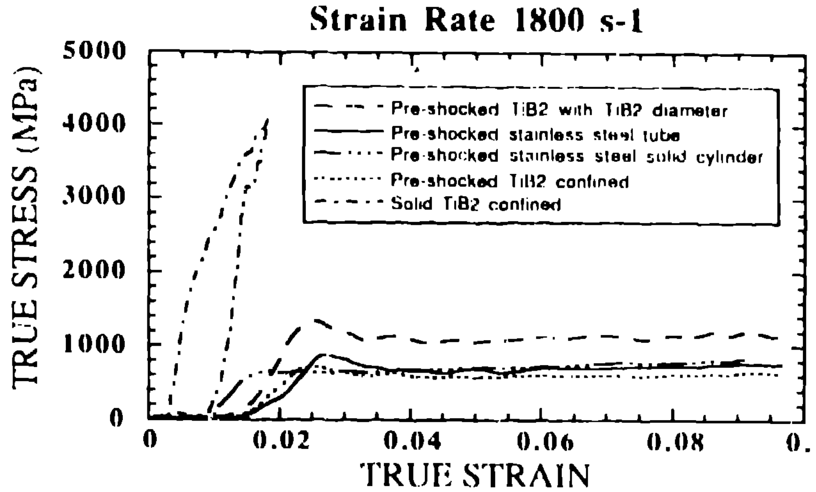


Fig. 6 High-strain-rate true stress versus true strain data obtained in a Hopkinson Pressure bar.

Only the solid $TiB_2$ confined in a stainless steel cylinder behaved elastically up to the 4000 MPa true stress. The pre shocked stainless steel cylinder and tube show the usual elasto plastic behavior. Two plots of the shocked ceramic represent data from the same test. For the plot labeled 'Pre-shocked $TiB_2$ with $TiB_2$ diameter', the data were reduced with the $TiB_2$ sample diameter. For the plot labeled 'Pre-shocked $TiB_2$ with SS tube diameter', the data were reduced with the outside diameter of the stainless steel container confining the pre-shocked ceramic. It is apparent from these data that pre-shocked, confined ceramic does not carry any load up to 10% strain. It is also apparent that the diameter used makes a significant contribution to data reduction. In order to facilitate reduction of the data obtained from the Hopkinson Bar tests, the system as shown in Figures 5 is being modeled using the EPIC-2 explicit finite element code. This is being done in order to examine the relative roles of the ceramic specimen and the stainless steel confining cylinder in this test and to determine an effective diameter to be used for data reduction.

## CONCLUSIONS

Presented results are preliminary but novel. We have designed a test in which the ceramic shock fracture processes are controlled and separated from the high strain rate compression by subjecting a confined ceramic first to a shock wave in a gun experiment and then to a high-rate compression in a Hopkinson Bar test. The gun test produced fractured ceramic which have not lost intergranular coupling and maintained nearly theoretical density. The pre-fractured ceramic showed no compression strength in the dynamic test using Hopkinson pressure bar.

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